DECISION SUPPORT AND INFORMATION SYSTEMS FOR REGIONAL DEVELOPMENT PLANNING

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Preface

This research report summarizes the results of a collaborative research and development project between IIASA's Advanced Computer Applications project and the State Science and Technology Commission of the People's Republic of China (SSTCC). The project's objective was to build a computer-based information and decision support system for integrated regional development planning in Shanxi, a coal-rich province in northwestern China.

By building on IIASA's experience in applied systems analysis, the project developed and implemented a new generation of computer-based tools, integrating classical approaches of operations research and applied systems analysis with new developments in computer technology and artificial intelligence in an integrated hybrid system, designed for direct practical application.

To provide the information required in the regional planning and decision-making processes, several databases, simulation and optimization models, and decision support tools were linked and integrated into one common framework with a consistent graphical user interface. Information directly useful to planners and decision makers is presented in a largely graphical and symbolic format for easy access and intuitive understanding.

The report summarizes the project, describes the problem area, the approach to integrated development planning, the design principles of the software developments, and the status of the prototype system as it was implemented in Shanxi.

The study was carried out with intensive collaboration between IIASA and several Chinese academic, industrial, and governmental institutions.

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Leader
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17.1 Introduction

The coordinated development of a region, its industrial structure in particular, requires the simultaneous consideration of numerous interrelationships and impacts (e.g., resource requirements, environmental pollution, and socioeconomic effects). Plans and policies for rational and coordinated development need a large amount of background information from various domains such as economics, industrial and transportation engineering, and environmental sciences. To be useful, this information must be presented in a readily available format, directly usable by the planner and decision maker. However, the vast amount of complex and largely technical information and the confounding multitude of possible consequences and actions taken, on the one hand, and the complexity of the available scientific methodology for dealing with these problems, on the other hand, pose major obstacles to the effective use of scientific tools and information by decision makers.

Computers, as well as new technologies such as expert systems, interactive modeling, and dynamic computer graphics, are becoming more widely available and affordable. This technology now makes it possible for powerful, accessible, and general software systems for complex regional problems to be built. These systems are designed to provide planners and policymakers with direct and interactive access to a large volume of information in combination with methods of scientific analysis.

The key components of this new generation of software systems emphasized by the Advanced Computer Applications (ACA) Project at IIASA are simulation and optimization models, representing the procedural, quantitative, and numerical assessment tools; data bases, containing nonspatial data; geographical information systems, providing access to spatial data, such as environmental properties, land use, infrastructure, resources, site-specific information (e.g., industrial plants, cities) etc.; expert systems, representing qualitative, symbolic, and logical assessment tools and knowledge about the problem domain; and graphical user interfaces, integrating the above into one coherent system and providing the user with interactive access.

The principles and concepts discussed in this paper are based on several application examples of interactive information, decision support, and expert systems in the area of regional development planning, including industrial restructuring, risk assessment, and environmental impact assessment. These systems were developed and implemented by ACA for policymakers and their technical and scientific staff or advisers at the international, national, and regional levels.

17.2 Regional Planning

Regional development planning is a complex procedure that requires input from numerous sources and usually involves a large group of people with different backgrounds and objectives. Physical planning, socioeconomic, technological, and environmental considerations have to be integrated in the design and planning of any development project.

Unfortunately, in addition to problems related to the planning of new projects, there is an increasing number of problems of containment and simply muddling-through regional crises and cleanup operations. Examples abound from failing infrastructure or employment problems in aging, inefficient and polluting industries, the cleanup of toxic waste disposal sites, and waste management of major cities and industries to acute cases of air and water pollution.

While the political and socioeconomic and institutional aspects may often be of dominant importance, there still is considerable demand for timely and relevant technical and scientific information. From an information processing point of view, these problem areas share the same characteristics. Planners and decision makers, and increasingly the general public, need and demand information as a basis for informed decisions. This includes background information to put the problem into context, from monitoring data to applicable standards. It also includes information on possible options, feasibility of courses of action and constraints, and finally an assessment of the likely consequences of any – or no – action.

This information needs to be provided in a format that is directly understandable and useful. Time is always important: we need the information immediately.

In several projects IIASA's Advanced Computer Applications Project has developed and implemented computer-based information and decision support systems on a regional scale:

- *A Regional Air Pollution Management System.* Sponsored by the CSFR Federal Commission for the Environment through the CSFR national member organization, a project to develop a regional environmental information system for air-quality management has been initiated. The system will provide interactive tools to display and analyze environmentally relevant information on a regional scale, and simulate and evaluate environmental control measures, including their approximate cost or investment requirements based on cost functions for various pollution-control technologies. The system will concentrate on air pollution from industrial sources, and will use several nested multilayer air-quality models, covering both the entire region as well as selected urban and industrial centers. In collaboration with appropriate institutions, the system will be used to address selected environmental management problems such as emission control options to meet specific environmental standards in northern Bohemia, in and around Usti nad Labem.
- *Regional Transportation Risk Assessment.* In collaboration with the Institut National de Recherche sur les Transports et leur Sécurité (INRETS) of the French Département Evaluation et Recherche en Accidentologie (DERA), a prototype system has been developed for the region

Haute Normandie. The interactive system integrates a path generator and risk assessment module with a set of data bases and a geographical information system.

- *Environmental and Technological Risk Assessment at a National Level.* In ongoing research for the Dutch Ministry of Housing, Physical Planning, and the Environment (VROM), the main emphasis of the current project phase is the continuing integration of several technological and environmental risk assessment models and tools into one coherent environmental information and decision support system. This includes new items such as an object-oriented GIS system for spatial analysis, data bases on major risk installations, sources of pollution, and a data base on hazardous substances. Safety reports as required by the recent incorporation of the Seveso Directive in Dutch legislation can be compiled and analyzed for both fixed installations as well as along transportation routes based on technological data and spatially variable population density, land use, and meteorological data.
- *A City-Level Information System.* The software was designed under contract to the city of Hannover, Germany, for environmental planning and management tasks. Funded by the German Ministry for Research and Technology (BMFT), the study involves several research groups and departments in the city's administration to develop and implement a decision support system in Hannover. The system covers all environmental media, as well as land use, by taking into consideration aspects of spatial planning (*Figure 17.1*).
- *EIA for Water Resources Development.* The rule-based expert system enables interactive rule-based environmental impact assessment for water resources development projects in the Lower Mekong Basin, combining qualitative and quantitative reasoning techniques with data bases and geographical information display. It has been designed and implemented under contract to the Mekong Secretariat, Bangkok, Thailand, sponsored by UNDP.
- *Expert System for Integrated Development.* In collaboration with the State Science and Technology Commission of the People's Republic of China, ACA worked on a case study of China's coal-rich Shanxi province. The system, designed under a two-year contract, combines data bases, and econometric, industrial, and environmental models with decision support tools. It was designed to assist the regional government plan for integrated regional development.

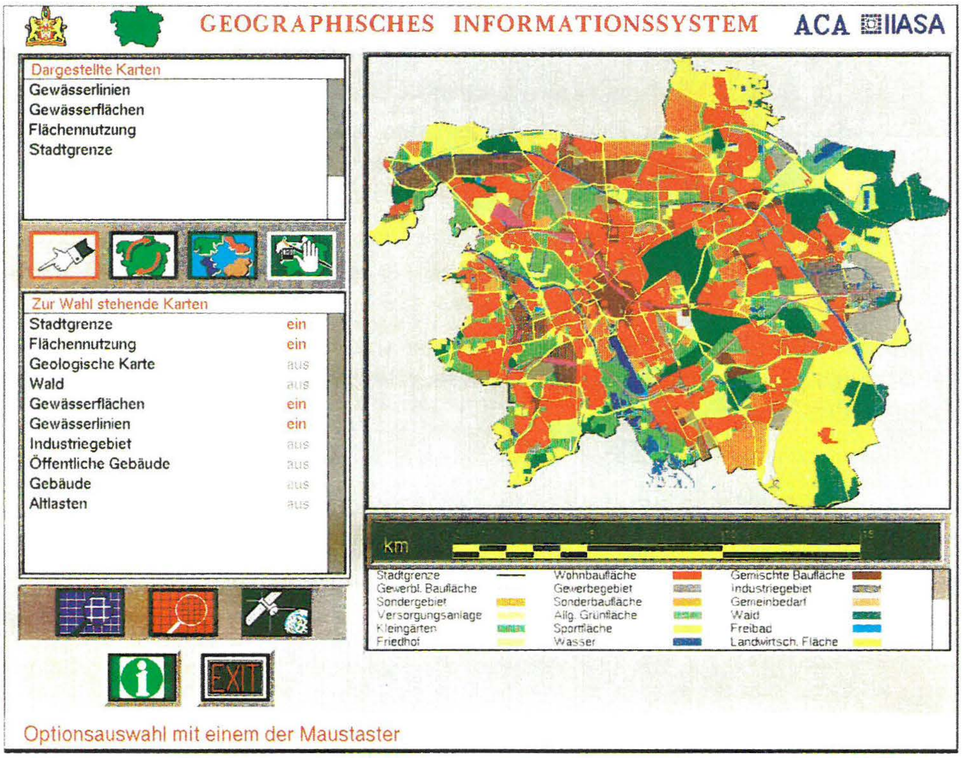

Figure 17.1. Geographical information system of the city-level information system for Hannover, Germany.

The Chinese case study is described in greater detail as one example of an integrated information and decision support system for regional development planning in Section 17.3.

17.3 The Shanxi Province Project

Within the context of a regional case study for the government of Shanxi province, the People's Republic of China, ACA has developed an operational *prototype expert system*, a model-based interactive information and decision support system with an intelligent, graphics-oriented user interface. Integrated artificial intelligence (AI) technology and components have been added to the system. This system was delivered and installed in Shanxi province in July 1988, where it was to be used by the regional government of the province for regional development planning.

The aim of the project was to develop an integrated system of software tools to make the scientific basis for planning and management directly available to planners and decision makers. Concepts of artificial intelligence coupled with more traditional methods of applied systems analysis and operations research are used. These tools are designed to provide easy and direct access to scientific evidence, and to allow the efficient use of formal methods of analysis and information management by nontechnical users as well. During the development process, a team of Chinese experts was trained to use and adapt the technology in the system, thereby encouraging user input and feedback from the start.

17.3.1 The problem

Shanxi is situated in the middle of central north China, a part of the country's northwest loess plateau, more than 1000 meters above sea level. Twenty-six million people inhabit 156,000 mostly mountainous or hilly square kilometers. While about a quarter of the area is arable land, more than a third is undeveloped or wasteland.

Shanxi is rich in mineral resources, including aluminum, iron, copper, and gypsum. The most outstanding resource is coal, with over 200,000 million tons of proven reserves and 860,000 million tons of estimated reserves. The coal is of superior quality, in stable, concentrated seams close to the surface.

As a consequence, Shanxi is China's powerhouse. It is the biggest coal producer in the country. The province's economy is very much centered on coal mining and energy production, with state-defined production targets. Most of the coal produced is exported, even though there are more profitable alternative uses of coal and downstream products which, in a more diverse industrial structure, could benefit Shanxi's economy and even help to reduce environmental problems. Restructuring the economy, however, needs capital, time, and good planning.

The strategic development plans for the province called for quadrupling industrial and agricultural output in the last 20 years of the millennium, to the year 2000. This should bring annual per capita gross output to about US $1000. The strategic plan explicitly addresses the integrated development of economy, society, and science and technology, as well as the importance of an ecological balance.

The main problem that makes this a difficult task is the low efficiency of Shanxi's current economy – an overrepresentation of heavy industry with labor intensive, low-profit technologies with little adaptability: a severe shortage of water resources, underdeveloped infrastructure (in particular, an insufficient transportation system), and a shortage of qualified and highly trained labor.

The government's task, which the system is designed to support, could be summarized as follows: to plan for integrated regional and industrial development centered on a primary resource (namely, coal), maximizing revenues from industrial production for a set of interdependent and increasingly diversified activities, subject to numerous resource constraints and externally set production targets and export goals, and to minimize external (i.e., environmental and social) costs.

17.3.2 Building blocks of development

Economic development and restructuring of a large region such as Shanxi province quite obviously cannot start from scratch. The existing economic structure, infrastructure, environmental and resource potential, and major constraints not only are important components of the problem, but also must be part of the solution. The current economic structure concentrates on energy and heavy, basic materials industry, as well as a still substantial agricultural component:

- *Coal mining and processing.* The coal deposits in Shanxi cover 57,720 square kilometers with an estimated reserve of 900 billion tons and proven reserves of 205 billion tons; the 1984 raw output was 187 million tons, and in 1985 reached 210 million tons, and is projected to continue to grow at about 7% annually.
- *Metal mining.* Mineral resources include iron, copper, aluminum, molybdenum, titanium, lead, gold, and silver.
- *Chemical industries (coking, coal gasification, liquefaction, coal-based fuels and feedstocks, intermediates).* Important chemical products include inorganic salts (sodium sulfide and sulfate), fertilizer, agricultural chemicals, and rubber.
- *Power generation (coal-fired) and distribution.* Concentrated around coal fields, large power stations generate more than 2.4 gigawatt at the Datong Second Power Plant, connected to the Datong–Beijing 500,000 volt high-tension power line; Shantou and Zhangze power stations contribute another 3 GW to the system.

- *Iron, steel, aluminum, and copper production.* The main producers are the Shanxi Aluminum Works, with a design capacity of 400,000 tons of aluminum, and the Taiyuan Iron and Steel Complex, with a broad production palette of 450 kinds of steel.
- *Industrial manufacturing.* This type of industry ranges from machinery (mining equipment, locomotives, hydraulic and electrical equipment, and bearings) to light industries (e.g., textiles).
- *Transportation (largely coal).* Only partly electrified the railway system in 1983 handled a freight volume of 138 million tons, including 118 million tons of coal; the road system currently includes a total of 28,700 kilometers "open-to-traffic," including about 23,000 kilometers of "all-weather" roads.
- *Agriculture.* Wheat, corn, and Chinese sorghum are the major crops; forestry, with about 16,000 square kilometers (more than one-third the result of recent afforestation), is gaining in importance.

17.3.3 Stumbling blocks to development

The possible courses of action for the development of Shanxi province are constrained by several external requirements or natural limits. Economic policies and production targets of the central government or the existing economic structure and the natural resource base of Shanxi province define limits and boundary conditions for the province. Internal and external boundary conditions and constraints include:

- *Capital for investment.* The 1984 level of investment was about 40 billion yuan, and the projected yearly growth rate for the province to the year 2000 is 7.5%; however, in line with the new economic policies, the balance between consumption and investment is under discussion.
- *Water resources.* Total volume of the province's yearly water resource (precipitation minus evapotranspiration) is 142 billion cubic meters; out of which about 64 billion cubic meters have been developed. The problem, however, is mainly one of location and distribution.
- *Transportation network.* The transportation network of railways and highways covers a total of 36,000 kilometers and is used intensively for the transportation of freight. However, the network is not sufficient to cope with the volume of freight. The low standard of construction and resultant bottlenecks in traffic movement impede the flow of commodities, causing coal to pile up around the mines.

- *Environmental degradation.* Although the quality of Shanxi's coal is very high, much of it is burned with rather inefficient technology resulting in air and water pollution. There simply is not enough water to dilute the waste generated.
- *Industrial labor force (3.5 million out of a total population of 26 million).* There is a shortage of skilled labor.
- *Export targets for coal and electricity.* By the end of the century the province plans to market (within China) 270 million tons in addition to 30 terawatt hours of electrical energy. This, particularly for electricity, places a severe strain on internal development, which also has increased demands for electricity.

Any balanced and sustainable development of the province has to take into account the above constraints and the existing economics and infrastructure. Further, while economic management policies seem to be changing, overall Chinese economic policies and progress also define limits to what the province can do on its own.

17.3.4 Aiding the planning process

To design and evaluate alternative development policies in terms of the above activities, objectives, and constraints, Shanxi's government needs not only a vision but information, concepts and plans, and tools to develop, test, and explore new policies without having to put them to a possibly very expensive real-world test. Computers and simulation models are the obvious answers.

As part of China's overall reform policies, the state and the provinces are changing their economic management practices, mainly with the objective of better overall planning, implementation of policies, organization, and coordination and use of economic means of regulation. With a new and changing system, there are several decision-making problems for the leaders of a province. To place the decision-making process on a more scientific basis, computer-based information and decision support systems have been recognized as necessary tools. This type of computer system is, unlike management information systems, not built for routine tasks, but specifically for decision support for long-range strategic planning.

The basic information requirements for decision support include:

- Background information on the *status quo* and likely development options, including interregional comparisons that can assist in formulating development objectives.

- Design and analysis of feasible development policies (optimization of individual activities, designing/optimizing sets of coordinated activities), including economic analysis (input/output, cost/benefit, for the regional economy and industrial activities or technology alternatives, respectively); resource requirements and allocation (e.g., water and capital); environmental impact analysis; and comparative evaluation of composite development alternatives (policy analysis).

To provide this information, and the tools for its analysis, several data bases, simulation and optimization models, and decision support tools were integrated into one software system. The information was to be presented in an understandable form, to be used directly by the province's planners and decision makers. The system is therefore structured along concepts of expert systems technology, includes several AI components, and features easy-to-use color graphics and a largely symbolic user interface.

17.3.5 The project's participants

In this collaborative project with the State Science and Technology Commission (SSTCC) and the Science and Technology Commission of Shanxi province (STC) the first project phase was spread over a period of two years. Prior to starting the research and development at IIASA, Chinese researchers had, through several research projects, collected and analyzed a considerable amount of background data on Shanxi province's economy and environment.

At IIASA, the project team was supported by two to four Chinese scholars, joining the team for periods ranging between three months and one year. These experts contributed to the system's development and testing, and, more importantly, provided the essential Chinese perspective. During this intensive on-the-job training, they quickly became familiar with the computer and software technology as well as the methodology.

In addition, several short-term visiting experts were invited regularly, bringing specific data and reviews of the work in progress. Toward the end of the project, a major review workshop, also involving a number of outside experts (e.g., from UNIDO and the IAEA), was convened.

Members of the IIASA team visited Shanxi province repeatedly to collect data and information and to install a first prototype at midterm and the final software system at the end of the project. Software installations, a weekly workshop, and a training seminar were run in parallel.

In addition to the work at IIASA, collaborating institutions in Poland and the GDR contributed by developing models and data bases for the project. Expert teams from Poland and the GDR visited China to present their contributions and train Chinese experts in their use.

The tools used for the study are based on IIASA's rich experience and the various problem domains relevant to the Chinese case study. In particular, the Advanced Computer Applications Project's set of software and development tools, including a large set of simulation and optimization model components and auxiliary software, and modular AI and graphics tools made it possible to develop and implement a very large software system, in such a short period, with more than 120,000 lines of code.

IIASA's unique role as an international and interdisciplinary institution provided an ideal setting for the project, where access to specific data, information, software, and expertise to a worldwide network of collaborators was made easy.

17.3.6 A blueprint for decision support

The integrated set of software tools developed for this project is designed for a group of users with diverse, including nontechnical, backgrounds. Its primary purpose is to provide easy access and allow efficient use of methods of analysis and information management that are normally restricted to a small group of technical experts. By combining numerical and symbolic methods, a synthesis of rigorous mathematical treatment and human expertise and judgment is obtained in a new generation of hybrid information and decision support systems.

The decision support system (DSS) is based on information management and model-based decision support. It envisions experts as its users, as well as policymakers; in fact, the computer is seen as a mediator and translator between expert and decision maker, between science and policy. The computer is thus not only a vehicle for analysis but, even more importantly, a vehicle for communication, learning, and experimentation.

The three basic, interwoven elements of the DSS are:

- To supply factual information, based on existing data, statistics, and scientific evidence.
- To assist in designing alternatives and to assess the likely consequences of such new plans or policy options.
- To assist in a systematic multicriteria evaluation and comparison of the alternatives generated and studied.

The system is characterized by methodological pluralism. The individual components of the system are based on different concepts, levels of aggregation, and methods of analysis – namely, numerical simulation, mathematical programming, symbolic simulation, interactive data base access, and rule- and inference-based information retrieval – all of which are integrated into one coherent system.

17.3.7 Making software smart

There is no generally accepted definition of what constitutes an expert system. However, analysts generally agree that an expert system has to combine a knowledge base (i.e., a collection of domain-specific information); an inference machine, which implements strategies to utilize this information and derive new conclusions (e.g., modus ponens, forward chaining, and backward chaining); and an explanation component or, in more general terms, a conversational interface that elicits input from the user and, on request, explains the system's inference procedure.

Obviously, an expert system must perform at a level comparable to that of a human expert in a nontrivial problem domain. The model for this expert system's design is therefore based on the concept of a team of experts, coordinated by a systems analyst, who orchestrates the tasks of the individual domain experts. Primary interaction is through the systems analyst, represented by the menu-driven and largely symbolic user interface. The user interface translates the user's request and specifications into tasks the system can perform, calls upon the domain experts (models and data bases), and communicates results to the user.

The expert systems approach has three major components:

- A conceptual or representation component. This is largely concerned with the user's perception of the system. The computer, through its software, must appear "intelligent"; interaction with the system must be natural, easy, and conversational, including all the subtle corrective feedback mechanisms used in human conversation. These concepts are implemented through the system's framework and structure, problem representation (drawing on declarative as well as procedural concepts), and the user interface design with its emphasis on symbols and graphics.
- A technological or implementation component. This includes all the techniques used to achieve these goals, i.e., the use of declarative languages and concepts in addition to the classical procedural ones, and the appropriate elements from the toolkit of AI research.

- A procedural or development component. The basic method behind this DSS is knowledge engineering and rapid prototyping together with well-established operations research and systems analysis techniques. Attempts were made to draw directly on the expertise of several collaborators, facilitating the structuring and integration of their input by using a series of prototype versions of the system's modules. This was used as a guide for the knowledge engineering and acquisition process.

17.3.8 The craft of software development

The development of a large and complex software system for a heterogeneous, and initially inexperienced (as far as the computer technology is concerned), group of users is a difficult task. Matching user's expectations and system's performance takes time, and is a learning process for the user as much as for the developer. Clearly, the user should get what he wants and needs.

Consequently, the development philosophy of this project is based on the concepts and approaches of rapid prototyping. Rapid prototyping can be understood as an experimental, adaptive, and highly interactive approach to software engineering. As an approach to software development and engineering, it is rapidly gaining popularity in academic as well as commercial environments. Rapid prototyping is ideal for a system's development whenever the developer is faced with a high degree of specification uncertainty – i.e., when detailed and rigid user requirements cannot be laid down, a priori, but are likely to evolve together with the system. Good applications for rapid prototyping are those that tend to be dynamic and interaction-oriented, with extensive use of user dialog. Decision support systems and systems designed for strategic planning problems have a high degree of initial specification uncertainty. Therefore, the efficient and continuing dialog between user and designer is essential.

The prototype implementations of the system's modules provide a specific abstraction method, a model, or a specific problem representation (language). They allow a domain expert or end user, who is rarely a computer specialist, to interact with the system with the help of a knowledge engineer and to understand better how his problem or expertise is represented.

The prototyping approach is incremental and iterative in nature. In the design employed, the numerous modules were initially developed independently, in small units that are easy to manipulate. The modular and open architecture of the overall system makes their integration easy.

Initial implementation of components usually leads, and certainly has led within this project, to repeated redefinitions of the system's components and functions, and redirection of emphasis. The frequent replacement of modules with increasingly improved versions is supported through standardized interface components. This relative independence of the modules is important for it eases the task of keeping the system current, adapting to the experience gained by its use, and extending its functionality.

Prototyping is usually described as a sequence of development cycles with distinct stages. In the case of a complex hybrid system with a large number of major components and a relatively large and, in fact, geographically distributed development group (code and/or data for the system have more or less simultaneously been developed at IIASA and in the PRC, the USA, Poland, and the GDR), these stages and cycles get blurred. The various components of the system are at different stages of maturity and have undergone differing numbers of development cycles.

In addition to the externally driven cycles defined by the feedback from the user, internal cycles driven by the cross-fertilization of the individual module's own development cycles are important. This, however, can also lead to situations where certain ideas or tools are implemented in some modules, but not in all others. The process of updating all other components, standardizing technical implementation standards, etc., is a time-consuming exercise and had to be traded off against further increases in the scope and functionality of the overall system. As a spin-off of the prototyping approach, this heterogeneity of parallel solutions provides a rich source of ideas and concepts for further development.

The most important aspect of rapid prototyping, however, is its role in shaping and in many cases even making possible a realistic and efficient dialog between the system's developers and users. It is a mechanism for the learning process of the user and the analyst or developer, and this learning aspect of the prototyping approach requires a common language of the prototype as an efficient communications tool.

The overall system is designed as a hybrid system combining classical data processing methodology and the methods of operations research and systems analysis with concepts and techniques of AI. Conceptually, the main functional elements of the integrated software system are:

- An intelligent user interface, which provides the user with access to the system's workings. This interface must be attractive, easy to understand and use, and to a certain extent translate human language to machine language and vice versa. This interface must also provide a largely menu-driven conversational guide to the system's usage (dialog and menu system), and several display and report generation styles, including color graphics and linguistic interpretation of numerical data (symbolic/graphical display system).

- An information system, which includes the system's knowledge and data bases as well as the inference and data base management systems, which not only summarize application- and implementation-specific information, but also contain the most important and useful domain-specific knowledge.
- The model system, which consists of models (simulation, optimization) that describe individual processes that are elements of a problem situation, perform risk and sensitivity analyses on the relationship between control and management options and criteria for evaluation, or optimize plans and policies in terms of the control variables' given information about the user's goals and preferences according to some specified model of the system's workings and rules for evaluation.
- The decision support system, which assists in the interpretation and multiobjective evaluation of modeling results, and provides tools for the selection of optimal alternatives with interactively defined preferences and aspirations.

Approaches, methods, and tools of AI and expert systems technology are embedded in the overall system at various levels and points:

- The object-oriented overall design and problem representation structures the integrated system along the concepts of expert systems.
- The user interface includes various elements of expert systems technology, e.g., natural language parsing, rule-based input checking and error correction.
- Throughout the system, context-dependent help and explain functions have been included.
- Selected model components are based on AI software engineering techniques, including a Lisp-model integration environment, a symbolic simulator for overall regional development, implemented in CommonLisp, and a site-suitability analysis tool implemented in Prolog.

Clearly, meaningful representation of a system as complex as a large region with its compound development problems exceeds the scope of traditional mathematical or statistical approaches. Precedents, or simply human expertise and judgment, have to be used where statistically derived evidence and hard observational data are missing, because the regional economic development planning field is obviously variable-rich but sample-poor. Many relationships may be known, in particular, from the technological and physical components of a regional system. However the consequences of yet untested policies, of behavioral responses to entirely new economic situations, and of changes in life-style and the very fabric of society can at best only be speculation. Intuition and experience will have to replace experiment and direct observation.

The number of potentially relevant variables is very large, and repeated systematic experimentation is virtually impossible. Innovative use of analogies, pattern matching, and common sense must fill this gap. Common sense rules; for example, it defines the constraints that resource availability imposes on development options or determines how political and cultural conditions shape development strategies. Integrating these representations of common sense, intuition, and experience with the traditional approaches of numerical analysis into one coherent framework is a major objective of the development of this expert system. Moreover, the role of the user and his interaction with the system are most important. For this tight man–machine interplay however, the system must provide the necessary intelligence to be acceptable to the nontechnical user. The tools must be sufficiently easy to use, so that the user can play a more active role, making it possible to configure and shape the system during use and thus also become a "system builder."

17.3.9 How it all fits together

All major modules of the system are available through the master menu. To keep the size of the executable modules low and in view of the demands of system's administration, all the major modules are designed as stand-alone modules.

In the current development version, which can be characterized as an operational prototype, the integration of the system's components is realized at several levels:

(1) Through a common user interface and implementation environment. This first essential step toward complete systems integration has obviously been successful. With all the system's components accessible through one master menu level, the interactive graphics interface, with

its consistent style in terms of layout and logic, common to all modules of the system, provides the first level of integration.

(2) Through a common data base. Here, however, only certain ad hoc solutions are provided. All of the models implemented have their own specific data requirements. They were originally developed independently of each other and were available for integration only very late in the project. As a consequence, models and their respective data requirements are largely incompatible with each other in simple technical terms (such as data formats) but also, more importantly, in conceptual terms. While the problem can easily be solved at the technical level, the implications of the conceptual differences would require either a complex system of interface and translation routines or the redesigning of all the modules affected in a compatible and consistent style.

(3) Through dynamically shared information. A few examples in the system show the possibility of model integration via pass files, allowing one module to use the output of another as input. This is straightforward in the case of dedicated pre- and post-processors and the respective models, such as MACEDIT and MACSIM or the PDA-GENERATOR, PDAS, and the PDA-INVEST investment scheduling programs. Others, such as the input–output modeling system, in themselves integrate several originally independent components such as the DISCRETE multiobjective optimization post-processor. It is, however, more complicated among models of different levels of aggregation and coverage. Conceptual differences and the lack of a common data base (e.g., the sites in PDAS and MITSIM, PDAS installations, and ISC industrial point sources) make a more thorough integration impossible at this point without redesigning the common data base and compatible system of hierarchical conceptualization for the entire system.

(4) Through a flexible, problem-oriented reconfiguration of functional components. Here KIM/INVEST provides an experimental example of an object-oriented model coupling, where the AI-based interfaces can overcome some of the conceptual incompatibility problems by appropriate knowledge-based adaptation of information passed between modules.

While the system in its current state certainly contains a considerable number of practical, useful components for the planning and decision making in Shanxi, the system, viewed as one integrated expert system, is at the stage of an operational prototype. Further development toward a full-scale pilot system and finally, a full-featured production system in day-to-day operation, not only will require additional time and effort, but also will require substantial input from the users themselves. A major function of the current prototype is to make it possible to acquire this input.

17.3.10 What the system can do

The information and decision support system in its current stage of development comprises 16 major modules (regional, sectoral, and cross-sectoral models); several of them include major subcomponents such as special-purpose editors, input generators, or data base interfaces. These major components include the following:

- The Knowledge-based Integration Manager (KIM) is an experimental version of a Lisp-based model integration manager and an important tool for further systems integration. Drawing on an object-oriented approach (Tompkins, 1986) and blackboard architecture (Hayes-Roth, 1983), KIM interactively coordinates the modules of the system. A pilot implementation, KIM/Invest, was developed for the problem-oriented study of investment distribution.
- The Macroeconomic Symbolic Simulator (MACSIM) provides the user with the possibility to conduct a dynamic simulation of the macroeconomic behavior of the Shanxi province, which, from this perspective, is viewed as the interaction of 22 macroeconomic sectors including production-oriented and nonproduction-oriented sectors, showing the outcome of the user's investment decision for each sector and for each timestep. The interaction between these 22 sectors is represented as the impact each sector has on the other sectors with regard to seven indicators. As a first step toward an interactive knowledge acquisition tool complementing MACSIM, a special-purpose editor MACEDIT was conceived, which facilitates a graphics-based modification of the indicator-specific cross-impact matrices of the system.
- Several classical econometric models (the I–O model system) of various degrees of aggregation range between 3 and 56 sectors. The system developed in the PRC includes interactive implementations of static, semi-dynamic, and dynamic models, including multicriteria optimization and scenario comparison modules.
- Global Investment Analysis (GLOBINV) for the integrated economic development of Shanxi was also developed in the PRC.
- Interregional Comparison at a Macroeconomic Level (COMP) compares different regions or different development stages of the same region at a

very high level of aggregation. A data base of basic and macroeconomic indicators for regional comparison is part of the system. The interface to this data base (with data of Shanxi province and several other Chinese provinces) serves to display the results of scenario analysis. In addition to the simple display of one region or two regions for direct comparison, several sorting and ranking options are available that allow specific features of any one region (existing or hypothetical, resulting from model runs) to be put into perspective.

- A Transportation System Analysis model (TRANS), developed in the PRC, allows for an optimization of the current transportation system, an analysis of current deficiencies, and an analysis of the investment requirements for capacity extensions.
- A Prolog-based model of spatial choice and siting (REPLACE, *Figure 17.2*) permits the exploration of feasible locations, requirements, or constraints for the siting of industrial or socioeconomic activities in a region. REPLACE can be used for any activity or project planned from any or all of the economic sectors considered, and is therefore difficult to categorize as either a sectoral or an intersectoral model.
- Industrial structure optimization (PDAS, *Figure 17.3*), a linear and spatially disaggregated optimization model, describes a broad set of industries, including mining, the energy production sector, chemical and metallurgical industries, and the building materials sector. The model uses an external hierarchical aggregation system that allows for selective high resolution while maintaining the model's broad coverage. It is designed to analyze and optimize industrial structures, i.e., the distribution of production capacities (and thus investments and resources) to obtain a certain set of products under specific boundary conditions (e.g., constraints on certain capacities or input materials) and to minimize or maximize criteria such as production costs or total revenues. The model is based on a mass conservative input–output approach and uses mathematical programming techniques to balance the material flows connecting technological processes or installations with each other and with the outside world (sources of raw materials and markets for final products). PDAS has its own data base interface, a program to generate a new model based on site and technology selections, and an investment-scheduling decision support system as a post-processor.
- The energy demand analysis model (MAED, *Figure 17.4*) by Chateau and Lapillone (1982), is a simulation model describing energy intensive industries in terms of their energy demand, basic economic behavior, and

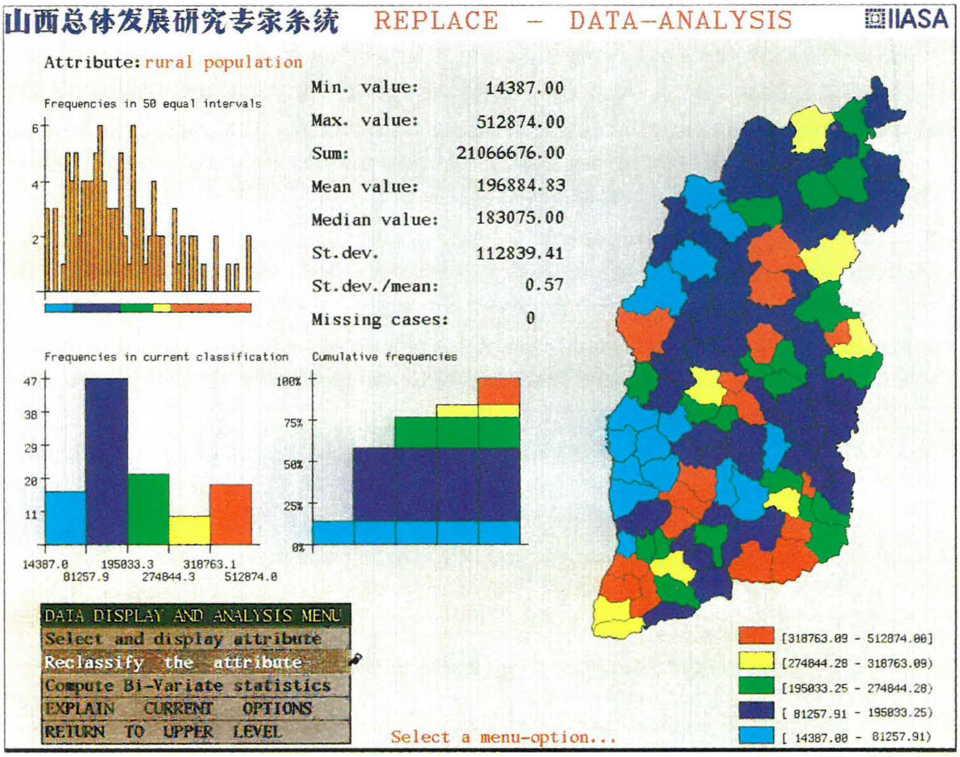

Figure 17.2. REPLACE: A Prolog-based model of spatial choice and siting

investment, as well as their water demand. MAED-BI deals primarily with basic and energy intensive industries, integrates several products, and provides a link with the macroeconomic level of each country or region studied. Three levels, and within them capacity exponents, can be selected to render economies of scale and technological discontinuities that occur between the possible capacity sizes at which a given production can take place. Specifically, by taking into account the huge potential of economies of scale, the model can describe discontinuous patterns of output growth in basic industries.

- Coal mine development (COAL), a global analysis model of the coal economy in Shanxi province, is based on dynamic simulation concepts, also developed in the PRC.
- A water resources analysis model (MITSIM, *Figure 17.5*) is a hydro-economic simulation model that provides a dynamic analysis of water

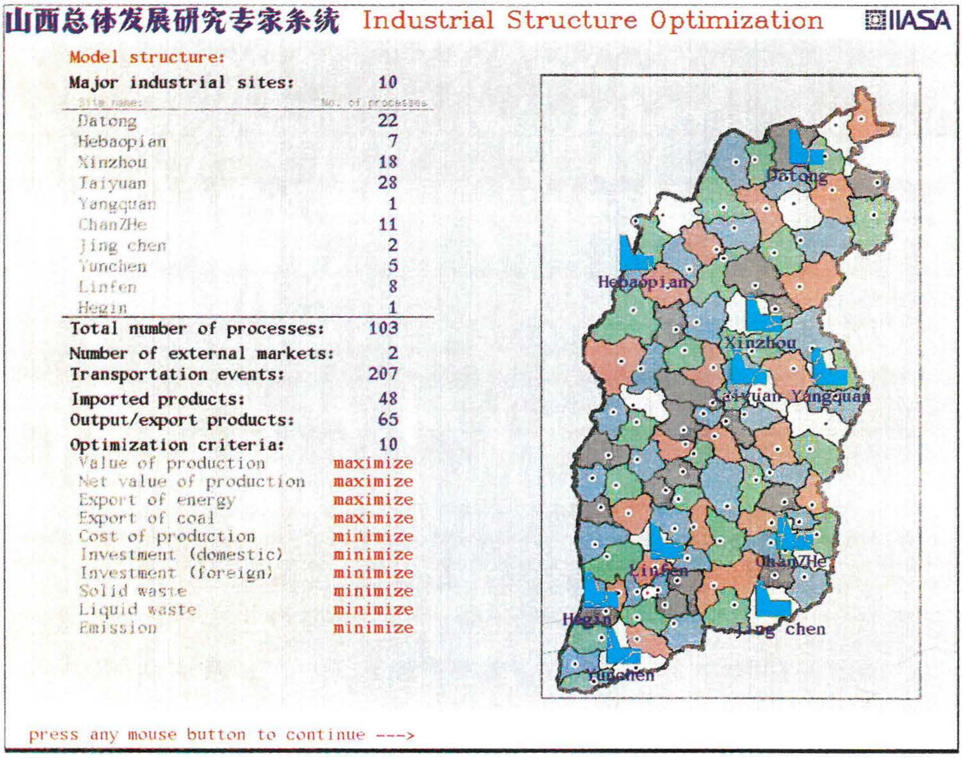

Figure 17.3. PDAS: Industrial structure optimization

demand–supply budgets for river basins. While simulating the water demand and allocation of a system of rivers, reservoirs, and diversion and groundwater wells, as well as the demand from municipal, industrial, and agricultural users, it evaluates a development plan, e.g., in terms of water availability and possible reallocation.

- The air pollution simulation model, based on EPA's Industrial Source Complex (ISC, *Figure 17.6*) model, is designed to calculate the short- and long-term ground-level concentration or total deposition of an inert pollutant on a local scale. It is based on an extended Gaussian plume equation of Pasquill (1961), describing the concentration or deposition of substances in time and space.
- The geographical and regional data base (GEO, *Figure 17.7*) module is part of the information system and provides interactive access to the contents of the system's geographical and regional data bases. Topics

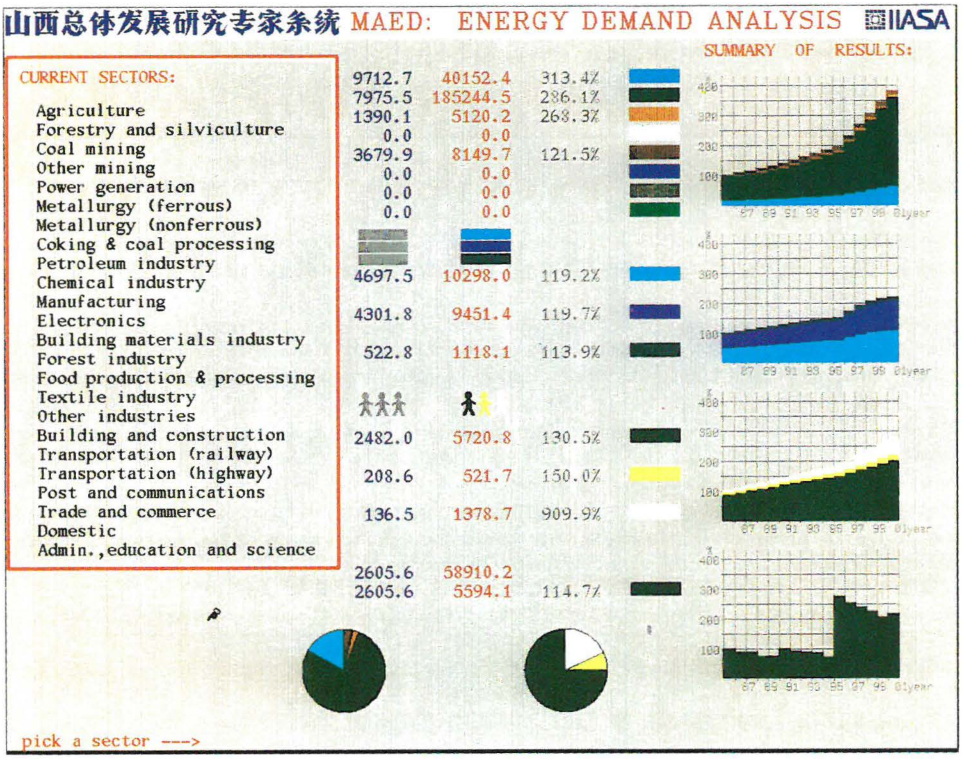

Figure 17.4. MAED: Energy demand analysis

such as mines, mineral resources, industrial locations, and road networks are represented graphically and in a list via the interface and different data base management tools that have been incorporated to provide the user (either the actual user or any of the system's models) with the information required.

- An investment distribution model (CONFRES) describing conflict resolution between urban and rural development in terms of investment distribution is based on the theory of cooperative games, and was developed in the PRC.
- A specific interactive and graphical stand-alone implementation of a discrete multi-criteria decision support system (DISCRETE) uses explicit optimization (one of the input–output model implementations and PDAS) and is based on the Dynamic Interactive Decision Analysis and Support System (DIDASS) approach. Developed at IIASA largely by

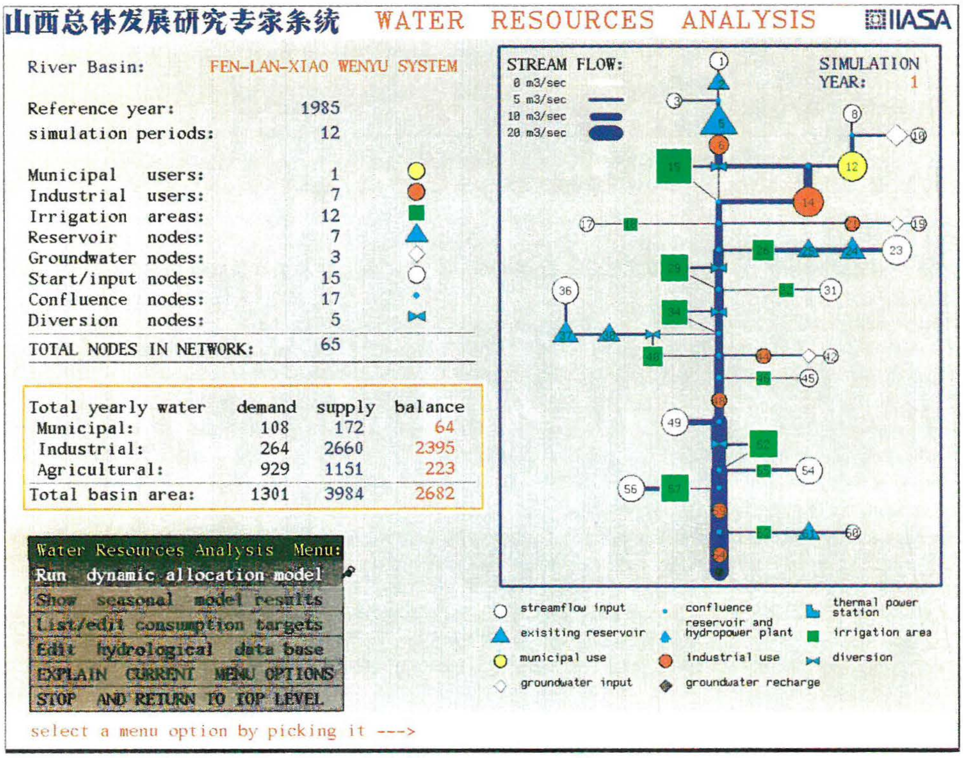

Figure 17.5. MITSIM: Water resources analysis

the System and Decision Sciences Program, it is based on methodology derived from the paradigm of satisficing decision making and the methodology of linear and nonlinear programming. The satisficing paradigm assumes that decision makers operate with targets in mind, which may be modified by accumulating information, and make decisions that reach, or come close to, these targets. In other words, rather than explicitly trading off individual criteria or objectives or formulating a composite utility function, a priori, the decision maker starts with a more or less clear, but complex and possibly intuitive, notion of what he wants, and then tries to get as close as possible.

These components, together with several auxiliary programs, have been implemented with a consistent user interface and numerous interconnections.

Figure 17.6. ISC: Air pollution simulation

17.4 The Future

The project was, among other things, as much a learning process for the users in the government as for the development team. As expected, specifications kept changing and the system kept growing until the final implementation in China. Numerous components and refinements deemed necessary or very useful were excluded and left for further development. The open architecture and modular structure of the software system supports this incremental development style. Adding and interfacing components is made easy by the standardized interface structure and several generalized utilities.

With further and more realistic definitions of user requirements, many of the system's current components and their relationships and integration will need to be developed. Essential future development will include changing the language of the interface from English to Chinese. Some modules already

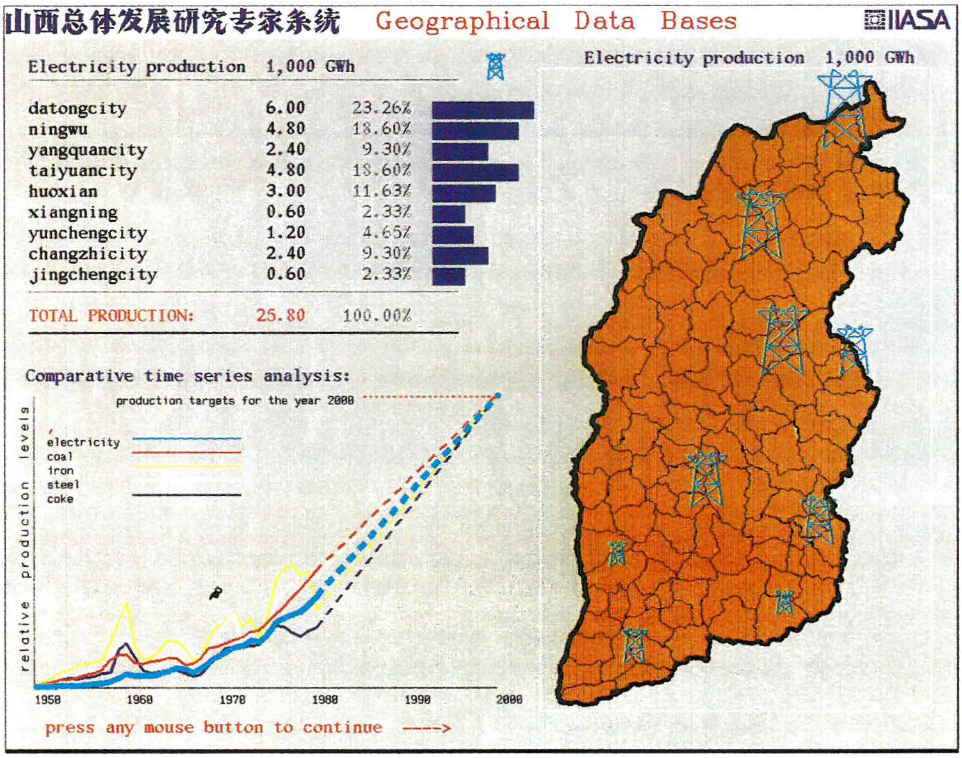

Figure 17.7. GEO: Geographical and regional data base

have some Chinese interfaces, and the symbol-oriented structure of the menu-driven interaction will make a further conversion a straightforward technical problem.

Another basic enhancement is a technically and conceptually unified common data base, in particular, a geographical information system (GIS) together with a more coherent conceptual framework implementing a consistent hierarchical structure of related geographical, technological, and economic concepts such as locations, production sites, installations, technologies or industries, or economic sectors. This common conceptualization and data base and the consequent modifications to the individual models are a precondition for a tighter integration of the system. Also, several additional new modules will have to be implemented, increasing the scope and coverage of the system – for example, in areas such as agriculture, demography, water quality, groundwater, and impact of science and technology on productivity.

The most important future development, however, will be the adaptation of the system to the lessons to be learned from its first applications. It is not just the task of system development itself, but also the analysis of so-called soft systems (typically, regional strategic planning) that must put much more emphasis upon learning and adaptation. Despite all the effort to produce a directly useful system, many modifications will be required to make the system more useful in its specific institutional and user environment. Since we expect the system itself to open up new possibilities of development planning and thus shape its own institutional framework, this new style of the planning procedure will lead to new requirements for the system.

Anticipating the need to change and adapt, providing the flexibility to learn from experience, and being able to listen and respond to the user and his requirements formulated in reaction to the prototype system are basic features of the overall approach. Rather than locking the user into the methodology of the system, it must invite modifications through its open architecture, keeping the cost of adaptation and replacements low. The system must be viewed as an approach or a philosophy as much as a product, or rather a set of tools that can be configured and reconfigured to meet ever-changing requirements.

The system is designed as a man–machine system in more than one sense. There is a never-ending process of system development. However, the institutional aspects (such as training the user, ranging from the technician to the top-level decision maker who does not have the time or the expertise to master the system) should not be neglected. Ideally, synergistic development at all levels (with the implementors, coordinators, analysts, model developers, programmers, economists, and statisticians working together with the users) would provide for truly viable systems.

Being intelligent also means being able to learn, and it is exactly this learning potential, the recognition that no formal system can ever be perfect but needs to be adapted to increasing experience and changing conditions, that adds a new dimension to the approach presented here. Only if the system is perceived as useful will it be used in day-to-day work and made an integrated element of the planning and decision-making process. Making it an attractive, flexible tool ensures that it will be used.

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